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PERFORMANCE MEASURES FROM TRACK GEOMETRY CARS:
In-Service Evaluation of a Dynamic Response L/V Predictor

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August 2007

TranSys Research Ltd

682 Milford Drive
Kingston, ON K7M 6B4

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Performance Measures from Track Geometry Cars:
In-Service Evaluation of a Dynamic Response L/V Predictor

by

G.W. English and T.W. Moynihan

TranSys Research Ltd
682 Milford Drive
Kingston, Ontario K7M 6B4

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Note on the units used in this report

Because the established practice within the North American railway industry uses imperial units for the basic measures of distance, speed and track geometry measurements, imperial units are used for those measures in this report. For speed and measurement intervals, which occur frequently throughout the report, equivalent metric units are not shown since they would detract from the flow of the text. A table of metric conversions for the units involved is presented below.

In the area of dynamic modelling of vehicle response, the use of metric units is standard practice; therefore, metric units are used for this in the report, with imperial equivalents shown where measures such as car weight are involved.

Conversion Factors	
Imperial Unit	Equivalent Metric Unit
1 in.	25.4 mm
1 ft.	0.3048 m
1 mi.	1.6093 km
1 ton	0.907 t
1 lb.	0.4536 kg (mass) 4.45 N (force)
degree curvature	Radius (m) = $\frac{1{,}746.375}{\text{degrees-curvature}}$

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16. Abstract

This report presents the results of the third phase of a test and analysis program aimed at developing better performance indicators for track geometry. The test program involved the installation of a software program *LVSafe*© on the track geometry evaluation cars of Canadian National Railway and Canadian Pacific Railway. The program predicts occurrences of undesirable lateral/vertical (L/V) force ratios for five car types at seven speeds. This phase involved the development of track geometry condition descriptors that underlie the undesirable L/V condition such that the site location could be located and repaired by field repair crews. It was concluded that the combination of GPS location coordinates and geometry condition description was adequate to locate and remove the L/V condition.

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16. Résumé

Ce rapport présente les résultats de la troisième phase d'un programme d'essais et d'analyse dont l'objectif est d'élaborer de meilleurs indicateurs de la performance de la géométrie de la voie. Le programme d'essais comportait l'installation d'un logiciel, le *LVSafe*©, à bord des wagons d'analyse de la géométrie de la voie des chemins de fer Canadien Pacifique et Canadien National. Le *LVSafe*© prédit les endroits où se produiront des rapports excessifs des efforts latéraux aux rapports verticaux (L/V), pour cinq types de wagons circulant à sept vitesses. Cette phase a aussi consisté à élaborer des descripteurs d'états géométriques de la voie qui mènent à des rapports L/V indésirables. Grâce à ces descripteurs, il est possible de repérer les endroits qui posent problème et d'y dépêcher des équipes de réparation. Il a été conclu que de conjuguer les coordonnées de positionnement GPS et les descripteurs de l'état géométrique de la voie était un bon moyen de repérer les rapports L/V indésirables et d'y remédier.

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Executive Summary

This is the third phase of a test and analysis program to develop better performance indicators for track geometry. Real-time wheel force prediction software has been developed to provide a true measure of the performance of track geometry. The computer program *LVSafe*© predicts occurrences of undesirable lateral/vertical (L/V) force ratios for five car types at seven speeds. In the previous phase, instrumentation and data acquisition systems were developed to collect geometry and test-car dynamic wheel force data. The L/V predictor (*LVSafe*©) that was developed has the capability to process geometry data in real time and predict locations that will produce high L/V ratios for several cars at multiple speeds and in both running directions.

While *LVSafe*© identified the locations where the combination of geometry conditions led to a high L/V, it did not define the underlying problem, nor did it prescribe a corrective measure. The objective of this phase of the research program was to determine a set of underlying geometry conditions that identify high L/V occurrences and to assess the ability of repair crews to locate and repair the geometry conditions as described in the *LVSafe*© printout.

The combination of GPS location coordinates and geometry condition description was found to be adequate for field crews to locate and repair the geometry at high-L/V sites.

A preliminary review of three derailment sites that occurred during the present data collection exercise indicates that *LVSafe*© has a much better risk-targeting performance than the existing defect classification system. Some questions arose with respect to each derailment report, and it is recommended that these and other derailments be reviewed in greater detail to get as much insight as possible from their occurrence.

The focus on the rail cars currently modelled within the *LVSafe*© software, which have mostly been empty cars, has proven successful because locations where loaded-car derailments have occurred have also been predicted by *LVSafe*© to have high L/V conditions for one or more of the modelled rail cars. However, there is potential to improve the risk targeting by adding car types.

Sommaire

Ce rapport porte sur la troisième phase d'un programme d'essais et d'analyse dont l'objectif est d'élaborer de meilleurs indicateurs de la performance de la géométrie de la voie. Un logiciel de prédiction en temps réel des efforts exercés par les roues a été développé, qui permet d'obtenir une mesure juste de la performance de la géométrie de la voie. Le programme informatique *LVSafe*© prédit les rapports excessifs des efforts latéraux aux rapports verticaux (L/V), pour cinq types de wagons circulant à sept vitesses. Au cours de la phase antérieure, une instrumentation et des systèmes de saisie de données avaient été développés pour colliger les données relatives aux efforts dynamiques exercés par les roues d'un wagon de contrôle de l'état géométrique de la voie et d'un engin TEST. Le prédicteur de rapports L/V (*LVSafe*©) traite les données géométriques en temps réel et repère les endroits qui produiront des rapports L/V élevés pour plusieurs types de wagons, à diverses vitesses et dans les deux sens de marche.

Le *LVSafe*© réussissait à déceler les endroits où la combinaison d'états géométriques menait à un rapport L/V élevé, mais il ne diagnostiquait pas le problème sous-jacent, pas plus qu'il ne prescrivait une mesure corrective. La présente phase de la recherche avait pour objet de déterminer des états géométriques précurseurs de rapports L/V excessifs, et d'évaluer la capacité des équipes de réparation de déterminer l'emplacement des états géométriques décrits dans la sortie imprimée du *LVSafe*©, et d'y remédier.

La combinaison de coordonnées de positionnement GPS et de la description de l'état géométrique de la voie s'est avérée un moyen adéquat pour les équipes sur le terrain de repérer les lieux présentant des rapports L/V élevés et d'éliminer ces facteurs de risque.

Un examen préliminaire des lieux de trois déraillements survenus pendant le présent exercice de collecte des données indique que le *LVSafe*© est de beaucoup supérieur au techniques actuelles de classification des défauts de la voie pour le ciblage des zones à risque. Chaque compte rendu de déraillement a suscité des questions; il est recommandé d'examiner en détail ces déraillements, et d'autres déraillements, afin d'en tirer le maximum d'enseignements.

Les wagons présentement modélisés dans le logiciel *LVSafe*© sont pour la plupart des wagons vides. Or, ce choix s'est révélé pertinent, car les lieux où sont survenus des déraillements de wagons chargés ont aussi été repérés par *LVSafe*© comme présentant des rapports L/V excessifs pour au moins un des wagons modélisés. Il serait toutefois possible d'améliorer le ciblage des risques en modélisant d'autres wagons.

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Glossary of Acronyms

AAR	Association of American Railroads
CN	Canadian National Railway
CPR	Canadian Pacific Railway
FRA	Federal Railroad Administration
HQ	Headquarters
IWS	instrumented wheel set
Kips	1,000 pounds
LT-F	lead truck forward direction
LT-R	lead truck reverse direction
L/V	lateral-to-vertical
MCO	mid-chord offset
Mtn.	mountain
NRC	National Research Council Canada
Pr.	prairie
TEC	track evaluation car
TT-F	trailing truck forward direction
TT-R	trailing truck reverse direction

1 INTRODUCTION

1.1 Background

The principal means deployed by all major railways in measuring the geometric quality of track is a track geometry car or track evaluation vehicle. While these vehicles are capable of measuring track parameters of interest, the interpretation of the measurements in assessing track condition and in deciding what to do about it varies widely and is in continuous evolution.

Most railways process their track geometry measurements on a short-segment basis in an effort to assess the overall level of quality. The processing provides a Track Quality Index, which is then used to trigger maintenance action at specified thresholds. The variances (or standard deviations) of geometry deviations are indices used by many railways as surrogates for quality. Variance provides a valid indication of track geometry "roughness"; however, it has limitations as a performance measure, the principal one being that vehicle dynamic response is very dependent on the wavelength of track deviation stimuli. Thus, a relatively smooth track segment at a critical wavelength may produce a more violent vehicle response than a rougher segment at a different wavelength.

Regulatory defects (or exceptions) are also derived from the track evaluation cars. These are local geometric conditions with thresholds–defined within the Canadian *Rules Regarding Track Safety*–that trigger immediate slow orders until maintenance action is taken. Defect definitions have evolved on a historical basis of judgement and derailment experience. A key factor in the present track geometry regulations is that they focus largely on single-measure perturbations. Track-vehicle dynamic interaction is speed dependent and can be influenced more by a series of small deviations at a critical wavelength than a single large perturbation.

1.2 Previous Phase

The present study follows two previous phases of research. In the first phase, low-cost instrumentation and broad coverage of the Canadian track network were used to identify the frequency of occurrence of undesirable vehicle response [TranSys Research, 2002]. Two car types (empty hopper and empty tank) were instrumented at the suspension points and traversed the railway networks of CN and CPR in a train consist with their track geometry cars over a 12 month period. "Bad-spot" predictor software was developed and has been successful in identifying locations of high dynamic action. The predictor model outperformed the existing regulatory definitions of "bad track" as a predictor of freight car suspension unloading. On Class 3 and Class 4 track, the number of defects identified was below the number of priority exceptions/defects reported by existing standards. For the initial definition of "undesirable", the number of occurrences for both cars, but especially the lighter hopper car, on Class 2 track was too high to be economically applied as a "corrective-action-required" indicator.

In phase two, field tests with an instrumented wheel set (IWS) were undertaken to assess the lateral and vertical wheel forces in addition to the suspension forces [TranSys Research, 2004]. A test route was selected to include Class 2 subdivisions that were found in the previous phase to produce a large number of unloading hits and a number of Class 4 mountain subdivisions with curvature up to 11 degrees.[1] An L/V wheel force predictor was developed that can process geometry data in real time and predict locations that will produce high L/V ratios for several cars at multiple speeds and in both running directions. The model demonstrated a high ratio of successful / false predictions of high L/V conditions for the test cars (see Table 1). Extension of the model's predictions beyond the test cars to other car types was also encouraging as it predicted high L/V conditions for several derailment sites that involved a range of different car types.

Table 1: Summary of phase-1 prediction accuracy for complete test route

Region	Measured Data			Model Predictions		
	Track Class	Data-miles	L/V > 1	Predicted	Missed	False Positives
Pr.	Class 2	100	15	14	1	12
Pr.	Class 2	60	3	2	1	1
Pr.	Class 3	50	0	0	0	0
Pr. + Mtn.	Class 4	136	0	0	0	0
Mtn.	Class 4	60	6	5	1	2
Mtn.	Class 4	116	0	0	0	1
Total		522	24	21	3	16

Legend: Pr. Prairie (maximum curvature 3 degrees).
Mtn. Mountain (maximum curvature 11 degrees).

1.3 Model Status

TranSys Research Ltd. has developed track performance predictor software to evaluate railway track performance based on predictions of rail vehicle dynamic response to track geometry as measured by track geometry cars. The software, *LVSafe*©, has been configured to identify track conditions that result in high L/V wheel force ratios for one or more of the car types that are included in the model. Each car is modelled at several speeds. The lowest speed for each car type was selected to capture the most severe response for that car type, while the higher speeds were selected to represent track class speeds. The highest speed evaluated is capped by the applicable speed limit for the segment of track being tested. The evaluation version of the *LVSafe*© model predicts responses for speeds up to 40 mph.

LVSafe© operates by windowing successive lengths of track geometry and calculating dynamic response of several car types/speeds over that track segment. The software evaluates

[1] Track classes are a regulatory term used to describe the tighter tolerances required for track geometry at increasing speeds. The maximum freight train speeds allowed on Class 1 through Class 5 tracks are 10 mph, 25 mph, 40 mph, 60 mph and 80 mph, respectively.

an entire subdivision by successively advancing the window along the track in discrete distance intervals. The model predicts hit sites where the L/V wheel forces reach undesirable levels. Since the dynamic response of the vehicle is usually triggered by a combination of events over a track segment length longer than the car length, these hit locations are at least 100 ft. long.

The development focus has been on rail cars believed to be more frequently involved in derailments where track geometry has been a contributing factor. The "bad actor" rail cars currently modelled within the *LVSafe*© software include:

- Loaded Hopper, 32 ft. Truck Centres
- Short Empty Hopper, 41 ft. Truck Centres
- Empty Hopper, 46 ft. Truck Centres
- Empty Hopper, 51 ft. Truck Centres
- Empty Tank, 54 ft. Truck Centres

The model identified the locations where the combination of geometry conditions led to a high L/V; however, the model did not define the underlying problem nor did it prescribe a corrective measure.

1.4 Objective

The objective of this phase of the research program was to define a set of underlying geometry conditions that characterize high L/V occurrences and to assess the ability of repair crews to locate and repair the geometry conditions as described in the *LVSafe*© printout.

1.5 Report Layout and Content of Subsequent Chapters

The balance of this report is divided into three chapters.

Chapter 2 outlines the L/V hit descriptions and recommended repair actions.

Chapter 3 is an assessment of the predictor's ability to target high-risk conditions.

Chapter 4 presents the conclusions and recommendations.

2 UNDERLYING CONDITION IDENTIFICATION

2.1 Identification Process

The development of exception descriptions was undertaken in concert with railway engineering departments. The descriptions were tied as much as possible to existing regulatory defect terminology. A trial and error process was used in which the high L/V conditions that were identified across the 20,000 miles of railways' track networks were classified by dominant type of car response. Each of the response types was then sampled to assess the signature of the track geometry that appeared to be contributing to the response.

All L/V sites involved multiple contributing factors. An algorithm was developed to extract the dominant factor at each site and to report that single factor for adjustment. In a trial and error off-line simulation process, the selected condition in the geometry data was smoothed out and the smoothed data used to rerun the model. By incrementally increasing the level of data smoothing and rerunning the model for a sample of like conditions, a repair guidance was developed for the principal underlying condition.

Since the L/V hit sites all involve multiple contributing factors and since only one is identified for repair, the repair guidance includes the underlying proviso that if the target for the identified condition cannot be met, then the other factors within the 100 ft. vicinity should also be smoothed out.

2.2 Geometry Exception Types

Four categories of geometrical features were isolated, which may contribute solely, or in various combinations, to the development of high L/V wheel force ratios for one or more of the five modelled car types. The hit categories, which have been confined to represent existing measurement practices, were:

- Rock and Roll
- Rate of Change in Elevation
- Lateral Ramp (with and without wide gauge or narrow gauge)
- Rise or Drop in Superelevation at Midpoint of 62 Foot Chord

All L/V hits detected while processing the track geometry for a subdivision are summarized within an output file having a name ending in "_LVSafe_Hit.txt". The name of each hit category is customized to suit the user's needs such that they closely reflect the terminology normally used by maintenance-of-way staff. A combination of several geometric conditions exists in all instances of L/V hit occurrence. The model attempts to interpret the contributors in order of highest to lowest significance and usually tries to restrict the output to the most significant condition. Because field crews are not as familiar with the lateral ramp condition as with the other conditions, preference is given to the vertical contributors in selecting model output. In some cases where the contributors are relatively equal in contribution, more

than one condition is identified. In all cases, the user is cautioned that other factors will always be present and if the designated condition cannot be reasonably repaired or is already within design thresholds, that the other factors in the vicinity be addressed. A brief description of each L/V hit type follows.

2.2.1 Rock and Roll

A *Rock and Roll Hit* identifies the distance over which alternating low sections capable of stimulating significant rocking motion of a target rail vehicle are present. These are signified by a "ROCKRL" declaration in both the CPR and CN implementations of *LVSafe*©. The recommended remediation is to restore the indicated track segment to its original design specification, or at a minimum, to raise the three worst low spots by at least 1/4 in. However, if a *Rock and Roll Hit* occurs in combination with a *Rate of Change in Elevation Hit*, then the geometry condition underlying the *Rate of Change in Elevation Hit* should be rectified, along with raising the two worst low spots by at least 1/4 in.

The ROCKRL defect is characterized by multiple occurrences of low spots on alternating sides (high and low cross level). While the railways' existing definition of Rock and Roll is associated with a specific threshold for six consecutive low joints, *LVSafe*© identifies ROCKRL as two or more low spots.

Posted Speed	DEF NUM	P/U	DEF NAME	T/B C/E	FROM MLG/FT	TO MLG/FT	LENGTH FT	MAX VAL	MAX LOC	GPS AT MAX VAL
40	4	Ut	ROCKRL		250 + 5120	250 + 4970	150		250 + 5042	51°50.4319N-110°4.6730W

Figure 1: Example of *LVSafe*© output for ROCKRL (CN implementation)

2.2.2 Rate of Change in Elevation

A *Rate of Change in Elevation Hit* identifies sections of track where the difference in track elevation — evaluated using a chord length equivalent to the truck centre distance of one of the rail car models — exceeds a calibrated threshold value. The maximum rate of change is reported to the nearest 1/8 in. In the CPR implementation, these are reported as "RC/##", where ## represents the associated chord length expressed in feet. In the CN implementation, these are reported as "WRP62@##", where ## represents the associated chord length expressed in feet.

While rate of change in superelevation is a design parameter in spirals, the defect is often reported in the body of curves. Since the repair condition is selected as one that removes the L/V condition without addressing other factors, the repair threshold is close to the design level in spirals of 1 in. in 60 ft. In severe conditions, the design rate for spirals can be as high as 1 in. in 45 ft. A tradeoff in developing the model was to report all contributing conditions and have a less stringent repair threshold, or select the largest contributor and have a more demanding repair threshold for that one factor. The present version of *LVSafe*© takes the latter approach and advises the user that if a 1 in. in 60 ft. rate of change is not feasible, then

alignment and cross level should be smoothed out at that location. Thus, remediation of a *Rate of Change in Elevation Hit* should strive to restore the indicated section of track to design conditions, or otherwise to try and obtain an equivalent 1 in. in 60 ft. rate of change. If that rate of change in track elevation cannot be attained, it is important to minimize the variation in cross level and/or gauge near the *Rate of Change in Elevation Hit* location.

Posted Speed	DEF NUM	P/U	DEF NAME	T/B C/E	FROM MLG/FT	TO MLG/FT	LENGTH FT	MAX VAL	MAX LOC	GPS AT MAX VAL
40	1	Ut	WRP62@41		254 + 4832	254 + 4777	55	1 1/8"	254 + 4799	52°52.4319N-118°4.7930W

Figure 2: Example of *LVSafe*© output for WRP62@41 (CN implementation)

2.2.3 Lateral Ramp

A *Lateral Ramp Hit* identifies locations where the rate of change in high rail alignment or gauge as measured over 10 ft. exceeds a calibrated threshold value. The maximum rate of change is reported to the nearest 1/8 in. In both the CPR and CN implementations, these hits are designated as "RCxx10", where "xx" is either "RA" for the right rail alignment, "LA" for the left rail alignment or "GA" for track gauge. *Lateral Ramp Hits* are often secondary contributors at locations where a mild cross-level perturbation exists. It is usually preferable to locate and repair the cross-level condition, although the track alignment can be corrected such that the rate of change is reduced to no more than 1/8 in. over 10 ft.

Posted Speed	DEF NUM	P/U	DEF NAME	T/B C/E	FROM MLG/FT	TO MLG/FT	LENGTH FT	MAX VAL	MAX LOC	GPS AT MAX VAL
40	6	Ut	RCGA10		243 + 877	243 + 869	8	0 5/8"	243 + 875	51°50.216N-108°6.730W

Figure 3: Example of *LVSafe*© output for RCGA/AL/AR (CN implementation)

The gauge/alignment ramp differs from the normal regulatory defects involving wide gauge and narrow gauge. It is the rate of change of alignment or gauge that is relevant to the L/V development. Since this characteristic is more difficult to interpret, it is used with a lower priority than the vertical geometry characteristics that contribute to high L/V forces.

The problems of identifying the characteristic to be changed are highlighted in Figure 4. Repair crews are accustomed to looking for the worst condition at a target location. For gauge it is usually the widest or narrowest, which in Figure 4 occur at 13.9135 and 13.866, respectively. The gauge ramp (rate of change) is also steepest at these locations. However, the horizontal geometry conditions identified as a problem by *LVSafe*© in this vicinity are the rates of change of both the left rail alignment and gauge at 13.898. While the left rail alignment's slope (or rate of change) at this location is indeed the worst case, it will not always be the case. Repair crews have to become accustomed to the concept that the characteristic being targeted is not the worst case, but because of its location with respect to

other geometry conditions produces a worse L/V result for traversing vehicles at that location.

As noted in Section 2.4, it was found that GPS coordinates and the indicated maximum value of the cited geometry characteristic were sufficient for crews to locate the problem. However, in all cases the crews were hesitant to accept the cited condition as a problem since there were many other "far worse" conditions to which they would normally give priority attention.

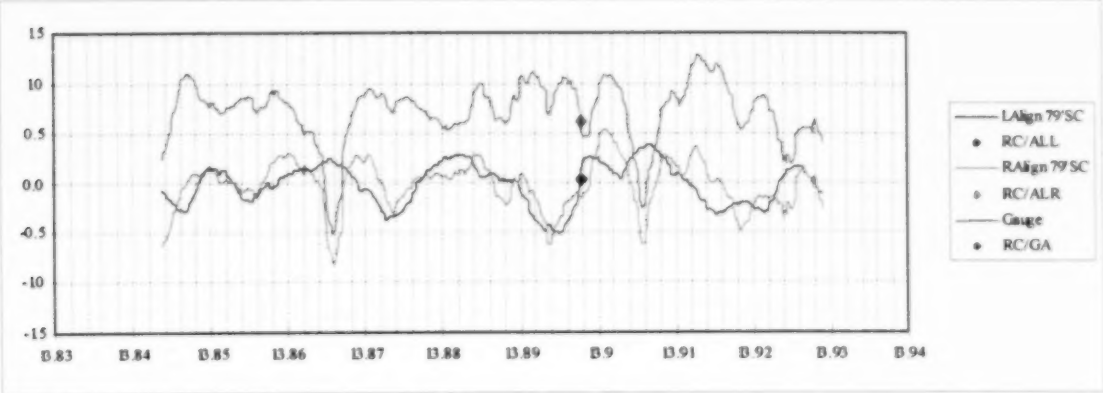

Figure 4: Alignment defect location illustration

There are several locations in Figure 4 that generate high lateral forces. At this time *LVSafe*©'s output identifies only those locations with a predicted high ratio of L/V wheel forces. At a later stage, it might be desirable to also indicate high lateral forces in isolation as an undesirable condition, but with a lower priority. Similarly, low vertical forces in isolation could be output as an undesirable condition but with lower priority.

2.2.4 Rise or Drop in Superelevation at Midpoint of a 62 Foot Chord

A *Rise or Drop in Superelevation at Midpoint of a 62 Foot Chord Hit* (SE62MC) identifies a bump or depression in the superelevation as measured at the midpoint of a 62 foot chord. It is determined by evaluating the difference in superelevation at the chord's midpoint from a value calculated by linearly interpolating the superelevation at the end points of the chord. As such, this condition is not detectible by work crews using a single measurement device as is the case with most other defects.

The SE62MC condition can sometimes involve WRP62## conditions at the same location. Repairing the SE62MC can be expected to also fix a WRP62## condition at the same location. If regulatory WRP defects are present at the same location, repairing the regulatory WRP defect will also fix the SE62MC hit.

Posted Speed	DEF NUM	P/U	DEF NAME	T/B C/E	FROM MLG/FT	TO MLG/FT	LENGTH FT	MAX VAL		MAX LOC	GPS AT MAX VAL
40	11	Ut	SE62MC		205 + 1203	205 + 1188	15	1	"	205+1201	51°50.216N-108°6.730W

Figure 5: Example of *LVSafe*© output for SE62MC (CN implementation)

2.3 Repair Guidance

High L/V occurrences are always due to a combination of geometry conditions. A single underlying factor might exist in many locations, but is only an L/V concern when combined with other factors at an identified location. Our approach was to identify the dominant condition at each location and, in many cases, not report the other contributing factors. In developing repair guidance, we undertook iterative simulations of hit sites with incremental smoothing of the dominant condition until the L/V condition was eliminated. Figure 6 provides an example of the header information that is printed out on every L/V-defect sheet provided to field repair supervisors. Note that the terminology is slightly different for the CN and CPR versions of header information to match the descriptions of geometry used on their respective railways.

LVSafe (c) copyright TranSys Research Ltd., 1996-2006
L/V Hit Detections for "TESTSUB_LVSafe_Geo.txt"
Notes: Mileage reported corresponds with those recorded within the track geometry file.

ROCKRL - Rock and Roll identifies the distance over which alternating low sections are present. Restore design specs, or at a minimum, raise the three worst low spots by at least 1/4".
- If WARP62@XX is also noted, raise two worst low spots and fix the WARP.

WRP62@## - Change in elevation over the specified chord length (## feet), rounded to nearest 1/8". Restore to design conditions, or try to meet an equivalent 1"/60' rate of change.
- If the rate of change identified above cannot be attained, it is important to minimize the variation in cross level and/or gauge near the WARP location.

SE62MC - Superelevation as measured at the midpoint of a 62' chord, rounded to nearest 1/8". Restore to design or reduce to at least the specified amount over the identified range.

RCGA/AL/AR - Variation in gauge and/or high rail alignment over 10'. Reduce the rate of change to be less than the specified amount over 10'.

Figure 6: Header text shown on each *LVSafe*© defect report (CN implementation)

2.4 In-Service Evaluation

2.4.1 Actively Monitored Subdivisions

The *LVSafe*© model was installed on both of CPR's Track Evaluation Cars and on CN's TEST car. The model ran on a separate computer that shared files in real time with the measurement systems' computers. Two files are generated by *LVSafe*© – one gives the defect description and milepost location, the other gives the GPS coordinates of the maximum value associated with the L/V exception.

CN and CPR each selected study subdivisions to be monitored in order to assess whether field forces could locate and repair identified L/V hit sites given the defect descriptions provided by the predictor model. Each took a different approach. CN passed the *LVSafe*© defect sheet out to the track supervisors on the study subdivisions and asked them to locate and repair the geometry condition as indicated. CPR designated a headquarters (HQ) track specialist to liaise with the track supervisors on the study subdivisions, to go with each supervisor to the indicated sites, and to assess the adequacy of the *LVSafe*© information in deciding what repair action should be taken.

CN selected adjacent subdivisions on its B.C. south line. The subdivisions were traversed three times during the monitoring period. On the first pass, one L/V defect occurred at a location that overlapped with a regulatory priority exception. The repair action taken prior to the subsequent geometry car run to repair the regulatory exception was also adequate in eliminating the condition identified by *LVSafe*©.

In the interval between the first and second geometry car runs, a new L/V condition developed. The defect did not overlap with any regulatory defined conditions. The field crew located the condition and undertook the repair action prescribed in the *LVSafe*© handout. The final run of the geometry car indicated that the L/V condition had been successfully located by the field crew and repaired. No new L/V conditions had developed and none were indicated for any locations on the three subdivisions.

CPR selected three subdivisions, each with different characteristics: one in the B.C. mountains, one north of Toronto, and one north of Lake Superior.

The mountain subdivision had three runs of the track geometry car. All L/V conditions in the first run occurred at priority or urgent defects and all were eliminated prior to the second geometry car run by the methods taken to repair the regulatory exceptions. One new L/V condition developed by the time the second pass was made.

The designated specialist and the local track supervisor successfully located the site and understood the prescribed action, but the repair action was not taken prior to the subsequent geometry car run.

The second test subdivision had two L/V conditions: one at a bridge transition, the other at a road crossing transition. Both conditions were readily located by the HQ specialist and the track supervisor, and the repair action was understood. The one at the road crossing was

successfully repaired prior to the subsequent geometry car run. The bridge location required action by the structures group and was not undertaken prior to the subsequent geometry run.

The third CPR subdivision was selected because of the high L/V count – it had 16 L/V conditions in the first pass of the geometry car. However, when the HQ specialist visited the subdivision, he found that all L/V defects had occurred where a tie-replacement program had been active. Ties had been replaced, but the final surfacing had not taken place at the time of the geometry car run. When the second pass of the geometry car was made, all L/V conditions had been successfully removed by the lining/surfacing actions undertaken as the final part of the tie program. No new L/V conditions had developed in the subdivision.

2.4.2 Passively Monitored Subdivisions

In addition to the sample subdivisions where *LVSafe*© hit locations were addressed, a number of other subdivisions were passively monitored. On these passively monitored subdivisions, no *LVSafe*© report was handed out, but the geometry runs were assessed for overlap of *LVSafe*© exceptions with similar conventional regulatory measures. Where there was overlap with urgent regulatory defects, subsequent runs over the same track sections were assessed to determine if repair of the regulatory condition was adequate to remove the L/V condition.

Table 2 illustrates the degree of overlap and repair success for three subdivisions that had varying levels of overlap with regulatory defects. For the Northern Ontario mainline subdivision, there were 16 L/V conditions and 67 regulatory defects detected for the first pass of the geometry car, and 62 percent of the L/V sites overlapped with regulatory defects. By the time the next geometry run was made, all of the original L/V conditions had been eliminated, and thus the repair success was 100 percent for both those that overlapped with regulatory defects and those that did not. In the interim, one new L/V condition and 10 new regulatory defects had appeared. One new L/V condition had developed at a new location.

The prairie secondary line (second location in Table 2) had 9 L/V conditions on the fist run and only 22 percent overlapped with regulatory exceptions. While 100 percent of the overlapping ones were eliminated by the second run, only 18 percent of those that did not overlap regulatory exceptions were eliminated. New regulatory and L/V conditions developed by the second run and at that time, only 15 percent of the L/V conditions overlapped with regulatory exceptions.

The mountain mainline (third location in Table 2) had only one regulatory exception on the first pass and three L/V conditions, none of which overlapped with the regulatory exception. One of the three L/V conditions (i.e. 33 percent) was eliminated by the second pass; however, by the second pass, one new regulatory exception and seven new L/V conditions had developed. One (11 percent) of the new L/V conditions overlapped with the new regulatory exception.

These results were expected since the *LVSafe*© output was not being handed out to field crews.

Table 2: Repair success at overlapping regulatory exceptions

Location / Track Class	N. Ontario / 4		Prairie / 2&3		Mountain / 3&4	
Geometry Car Pass	First	Second	First	Second	First	Second
Regulatory Exceptions	67	10	99	140	1	1
LVSafe Defects	16	1	9	13	3	9
% Overlap	62%	0%	22%	15%	0%	11%
% Repaired (overlap)	100%		100%		N.A.	
% Repaired (no overlap)	100%		18%		33%	

2.4.3 Conclusions for Canadian Mainline Track

It was found that, where the *LVSafe*© defects did not overlap with regulatory defects, the *LVSafe*© defect description and prescribed remedial action were adequate for the track supervisor to locate and take repair action. A track supervisor noted that the magnitude of the defined defects was not as bad as others in the same region and would only be repaired by track gangs if they were instructed to do so (by defining them with sufficient action priority).

In general, it was found that if the L/V condition overlapped with a regulatory geometry condition of the same nature, then repair of the regulatory condition also removed the L/V condition. When relevant priority defects were present at an L/V defect, repairing the priority defect removed the L/V defect (for second-pass test subdivisions as well as for second-pass non-test subdivisions where LV defects were not handed out).

3 RISK TARGETING

Derailments occurred on a number of passively monitored subdivisions during the course of the data gathering. These occurrences were used to assess the risk targeting attributes of the model. Since the data were not available for some areas within the time constraints of the study, a fuller analysis of all derailments is recommended. Three derailments that occurred in the earlier stage of testing and where geometry runs had been undertaken with *LVSafe*© running were assessed. The relative effectiveness is reported below.

3.1 Derailment Site-1

3.1.1 Characteristics

The derailment occurrence involved the following characteristics:

- Class 2 track
- Continuous welded rail (CWR)
- First car off was a loaded hopper car
- Train speed was 24 mph

The derailment cause was described as "rock and roll" and the cause code was:

T102 – irregular cross level (not at joints)

The first car to derail was a loaded hopper car (estimated truck centres 54 ft.). The derailment occurred three weeks after the geometry car run and the derailment location was cited as "within the curve" at MP-119.8.

The geometry car's location is manually input and monitored and can vary from the actual location by a few hundred feet. The geometry car data showed MP 119.8 to be between the two sides of 6-degree reverse curves. Since the derailment was reported to occur "within the curve" it is not clear in which of the two curves it actually occurred. *LVSafe*© indicated a Level-3 hit for the 51-ft. truck-centres, empty hopper car at 25 mph due to Rock&Roll within each of the curves. One of the L/V-hit locations overlapped with a priority over-elevation in curve defect and the other had no regulatory cross-level defects but did have a priority WG defect. It would be desirable to determine exactly which curve was the location of the derailment. It would also be desirable to characterize the derailing loaded car and assess the L/V predictions for it.

3.1.2 Risk Targeting Comparison

In terms of the existing risk targeting, *LVSafe*© identified 53 locations that were predicted to stimulate undesirable L/V responses in the 140 mi. subdivision in which this derailment occurred. One of those locations experienced a derailment. In comparison, the combination of railway-internal and regulatory defects identified 1843 priority-defect locations.

Depending on the actual point of derailment (POD), either one or none of them were present at the derailment site.

With *LVSafe*© as a repair criterion on this subdivision, 53 sites would have been repaired and one derailment would have been prevented. Under existing regulatory definitions, close to 2000 sites would have required repair and the derailment might or might not have been prevented (depending on the actual location of the POD).

3.2 Derailment Site-2

3.2.1 Characteristics

The derailment occurrence involved the following characteristics:

- Class 2 track
- Continuous welded rail (CWR)
- First car off was a loaded box car
- Train speed was 25 mph

Two different derailment cause codes were provided by the two different railways involved:

T221 = broken rail-vertical split head (reported by train operator)

T113 = wide gauge due rail wear (reported by track owner)

The first car to derail was a loaded box car (estimated truck centres 41 ft.) and the derailment occurred two months after the geometry car run. The broken rail reported by the train operator was indicated to have occurred on a section of tangent track, while the location reported by the track owner was in a curve that had been identified as having an urgent wide-gauge (WG) defect by the prior geometry car run. The urgent regulatory defect involved a slow order until it was repaired and would have been repaired by time the derailment occurred two months later. *LVSafe*© indicated a Level-1 hit for two different car types at that location. The combination defect included a high rail alignment ramp and gauge ramp. The regulatory WG condition could have been repaired without changing the rate of change exhibited by the high rail's alignment, which was the source of the L/V hit.

3.2.2 Risk Targeting Comparison

If the track owner was correct in assessing cause, the urgent WG defect would have been repaired, but its repair would not have eliminated the undesirable L/V condition. *LVSafe*© did not include a model of the loaded car involved, but did predict a Level-1 L/V condition for several empty cars at 25 mph. If Level-1 conditions had been repaired for this 130 mi. long subdivision, 88 locations would have required repair. In comparison, 2896 railway-internal and/or regulatory defects would have had to have been repaired, and as noted in Section 3.1, would not have prevented the derailment, even though an urgent regulatory defect had been present.

As with the previous derailment, the model predictions for this loaded car would be of interest. In particular, a Level-3 L/V condition for the loaded car at that location would elevate its priority over the Level-1 condition predicted for the empty car that is currently modelled for that truck spacing.

Of particular interest in both of these derailments is the change in risk targeting that occurs with additional car types. There were 35 Level-3 L/V locations compared with 88 Level-1 L/V locations. *LVSafe*© might achieve better risk targeting by having more car types and generating direct Level-3 conditions, rather than depending on the present five recognized "bad actors" that predict a Level-1 L/V condition for the same site.

3.2.3 Uncertainties

There are a number of aspects that warrant follow-up. First, the actual cause of the derailment needs to be verified (i.e., was it broken rail as reported by the equipment operator or the wide gauge as reported by the track owner?). If it was broken rail, it is not relevant to *LVSafe*©. If it was the track condition at the track owner's reported location, then it is relevant to *LVSafe*©. Another aspect to be addressed in follow-up is whether inclusion of the loaded car type would elevate the L/V hit from Level-1 to Level-3. Also, the importance of repair techniques for wide gauge conditions would be highlighted if the derailment was due to geometry condition in the curve rather than broken rail in tangent. *LVSafe*© gives priority to surface conditions when identifying repair action because the underlying condition can be readily related to existing regulatory standards. The alignment defects are given a lower priority because there is a chance they will not be understood or repaired. The lateral force is determined more by inflection points and rate of change than from the absolute level, which is the focus of the regulatory definition of wide gauge.

3.3 Derailment Site-3

3.3.1 Characteristics

The derailment occurrence involved the following characteristics:

- Class 3 track
- Continuous welded rail (CWR)
- First car off was an empty hopper car

The derailment cause code was:

T102 = cross level irregular (not at joints)

Emergency brakes kicked in as the train was pulling through a switch. Upon inspection it was determined that a wheel on the 69th car had derailed 4 miles back "in a curve with a 3.5 in. superelevation problem" and travelled to the switch location, where it separated the train. The speed was reported as 7 mph, which would have been at the time of emergency

braking at the switch. The speed at the initial wheel derailment location could have been anything up to the 40 mph speed limit at that location.

The geometry car had tested that subdivision three months earlier. A 3.4 in. superelevation in a curve existed 150 ft. farther up track than the reported derailment location (which is a reasonable error band in reporting) and is assumed to be the derailment location. *LVSafe*© predicted a Level-1 L/V condition for the empty hopper car at 40 mph at that location.

3.3.2 Risk Targeting Comparison

A priority cross-level defect existed at the same 3.4 in. superelevation location at which *LVSafe*© predicted a Level-1 L/V hit. On this 130 mi. subdivision, *LVSafe*© identified 67 locations with Level-1 or greater L/V conditions, one of which appears to have resulted in a derailment. In comparison, the combination of regulatory and railway-internal definitions of defects resulted in 2616 priority or greater defects.

3.3.3 Uncertainties

It would be desirable to get additional details on the derailment in order to better understand the reason for a lower L/V prediction at the derailment site than was predicted elsewhere on the subdivision without ensuing derailments. Since the derailing wheel occurred 4 miles from a turnout that the train took at 7 mph, it is possible that the train was going 40 mph at the initial wheel derailment location. It is also possible that a brake application was initiated at the initial derailment location and contributed dynamic forces beyond the geometry-induced forces. Additional details of the train speed and terrain could provide insight to the occurrence and the reason for a Level-1, rather than a Level-3 L/V hit prediction.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 L/V Defect Location and Repair

The combination of GPS location coordinates and geometry condition descriptions provided by *LVSafe*© defect reports was found to be adequate for field crews to locate and repair the geometry at high-L/V hit sites. Also, an analysis of second-pass geometry measurements of both test subdivisions and non-test subdivisions (those where no L/V defect information was provided to track maintenance staff) shows that when relevant priority defects coincide with an L/V defect, repairing the priority defect also removed the L/V defect condition.

One area of feedback received was a concern that the recommended repair actions are very close to, and might even exceed, design conditions in some areas. The field crews also noted that if two factors were present at one site they might plan on using different equipment than if only one factor were present. The repair guidance was developed through an iterative trial and error process from the viewpoint of which action would remove the L/V condition in all circumstances if only one condition was addressed. Multiple factors are present at every L/V condition and it would be desirable to revisit the thresholds to indicate at least two of the contributors such that less demanding individual thresholds can be specified.

4.2 Risk Targeting

There is often some degree of overlap with existing railway-internal definitions of track defects, although not always at the regulatory threshold. The railways' use of priority defects to identify potential problems is much less effective at targeting high L/V conditions. Prior IWS testing found that high L/V conditions occurred at locations without any regulatory defects and that regulatory defects were present at locations without high L/V conditions. The preliminary review of three derailments that occurred during the present data collection exercise indicate that *LVSafe*© has a much better risk-targeting performance than the existing defect classification system. Some questions arose with respect to each derailment report, and it is recommended that these and other derailments be reviewed in greater detail to get as much insight as possible from their occurrence.

The focus on "bad actors", which have mostly been empty cars, has proven successful because locations where loaded-car derailments have occurred have also been predicted by *LVSafe*© to have high L/V conditions for one or more of the modelled "bad actors". However, there is potential to improve the risk targeting by adding additional car types. If new car types generate a higher L/V condition than the currently modelled car types at derailment locations, or identify other locations that are not currently predicted to have high L/Vs, then their addition will provide improved discrimination. It is recommended that derailment occurrences involving different car types be used in an ongoing validation of new car types within the model.

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